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François-Xavier Delmonteil
Marie-Eve Rancourt

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Université de Montréal
Pavillon André-Aisenstadt
C.P. 6128, succursale Centre-ville
Montréal (Québec)
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Téléphone : 514 343-7575
Télécopie : 514 343-7121

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Analysis of Space-Based Technologies Deployment in Emergency Operations Management: A Case Study of the Post-2010 Haiti Earthquake Response

François-Xavier Delmonteil[1,*], Marie-Ève Rancourt[2]

[1] Center for Management Research, École Polytechnique, bâtiment ENSTA, 828 Boulevard des Maréchaux, 91762 Palaiseau, France

[2] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT) and Department of Management and Technology, Université du Québec à Montréal, P.O. Box 8888, Succursale Centre-ville, Montréal, Canada H3C 3P8

Abstract. The scale of damage caused by disasters is increasing and the provision of aid is becoming more complex owing to uncertain crisis conditions. These issues require the adoption of new alternatives for adapting to dynamic environments and achieving effectiveness in emergency operations. In this context, technology can facilitate the transformation of isolated relief supply chains into coordinated and resilient delivery channels in catastrophic settings. We present a case study supported by information gathered from semi-structured interviews and a questionnaire survey on the benefits of using space-based technologies, as experienced by relief operators during the 2010 Haiti disaster response period. The primary findings demonstrate that major logistical challenges were facilitated by space-based technologies, which provided relief teams with a more comprehensive and near real-time picture of the events occurring on the ground. However, in high pressure, rapidly changing operations, often in insecure and dangerous conditions, relief workers have little space to innovate new ideas. The effective implementation of such novel technologies requires more upstream training and resource investments.

Keywords: Space-based technologies, disaster relief logistics, emergency operations, humanitarian supply chains, Haiti earthquake response, case study.

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* Corresponding author: francois-xavier.delmonteil@polytechnique.edu

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1. Introduction

Most catastrophes occur unexpectedly and provide little scope for disaster preparedness. Therefore, the flexible and timely deployment of response capacities is crucial for saving lives in the immediate hours and days following a major catastrophe (Ichoua, 2010). Managing and coordinating relief supply chains is becoming increasingly difficult as the scale, dynamics, and complexity of disasters and supply chain structures increase (King, 2005; Blecken and Hellingrath, 2008). This high level of environmental uncertainty and organizational pressure can lead to serious problems by delaying relief supplies and eventually inducing environmental degradation and additional health problems among affected populations (Karunasena, 2011).

The extreme complexity of a catastrophe creates a need for proactive risk management within supply chains to ensure real-time recognition of and response to unplanned events (Wagner et al., 2009). However, acquiring information regarding the ground situation can be extremely challenging in such environments. In particular, disasters create information barriers, low visibility, and difficulties in terms of sizing and locating requirements. Many researchers such as Lee et al. (2004), Child (2001), and DeSanctis and Monge (1998) argued that technology can facilitate coordination through a higher degree of information flow exchange and integration. From a logistical perspective, Sheffi (2001) observed that technology can enhance visibility and decrease overall uncertainty. Deployment of several technologies can enable humanitarian organizations to manage the complexity of catastrophic disasters by assisting coordination and improving aid delivery (Conti, 2008; Varvas and McKenna, 2013).

This case study proposes an empirical analysis of the deployment of space-based information and communication technologies for operations management, as experienced during the post-2010 Haiti earthquake response. As far as we know, very few studies have investigated the full impact of technology in humanitarian supply chains. Furthermore, no paper has been published on the specific role of space-based technologies in the context of disaster response. Thus, we used a case study-based methodology because it facilitates the formulatation of research problems and hypotheses (Fisher, 2007) and provides exploratory depth of complex and unfamiliar phenomena (Benbasat et al., 1987). In particular, Pedraza Martinez et al. (2011) mentioned that case study is useful to investigate the complexity of the humanitarian crisis and to explore new theoretical ideas. As suggested by Barratt et al. (2011), an inductive qualitative case study approach can be adopted to develop and extend theories using contextually rich

data. Multiple methods and tools for data collection can be used in case study such as interviews and questionnaires (Meredith, 1998; Stuart et al., 2002).

Analyzing the role of space-based technologies during the response period of the Haiti crisis is of crucial interest for three main reasons. First, the Haiti crisis was an incremental step toward humanitarian organizations that pioneered using space-based technologies in emergency operations. Second, it represents one of the most catastrophic and challenging events ever encountered by the international community (Pedraza Martinez et al., 2010). Government institutions were completely decapitated, which resulted in the mobilization of hundreds of international relief organizations. As observed by Holguín-Veras et al. (2012), the scale of a disaster is one of the most important determinants of the deployment of response capacities. A catastrophic disaster, such as the Haiti earthquake, destroys local capacity, consequently crippling a community's ability to respond. In particular, national infrastructure such as ports, airports, roads, and telecommunication networks can be severely damaged or destroyed (Fuhrmann et al., 2008; Koudelka and Schrotter, 2007). The destruction of important support systems often impedes communications with the affected population (Holguín-Veras et al., 2012; Koudelka and Schrotter, 2007; Van Wassenhove et al., 2010). Third, the first few months after the Haiti crisis represent a time horizon during which infrastructure was not yet restored, increasing pressure on relief organizations that struggled to provide vital aid to affected populations. In sum, the post-2010 Haiti earthquake period was a critical time span that posed several logistical difficulties, and technology was crucial to support the relief organizations.

Despite the intensity of the Haiti earthquake, fewer studies have examined the effectiveness of the technologies that were used to support relief operations during the crisis. Our case study aims to bridge this gap and its purpose is threefold. First, it provides an overview of the main logistical challenges faced by relief workers during the 2010 Haiti crisis. Second, it highlights the benefits of four space-based technologies to logistical activities. Third, it identifies limits and barriers to the deployment of space-based technologies and potential negative externalities on logistics. Thus, this empirical study enables logisticians and managers to understand the extent to which such advanced technologies benefit relief operations management and the mechanisms that could improve their implementation and the level of benefits. The study was conducted through both semi-structured interviews and a questionnaire survey.

The rest of this study is organized as follows. Section 2 reviews the literature covering the importance of technology within complex humanitarian supply chains. Section 3 describes

the empirical research framework. Section 4 presents the results and an overview of the benefits and difficulties related to the use of the four foremost space-based technologies. Section 5 discusses cross-analysis findings and provides recommendations for improved deployment of space-based technologies during an emergency response. The last section concludes and presents the limitations of this study and implications for future research.

2. Literature review

Uncertainty is a major challenge of humanitarian operations management and is linked to organizational capacities, the demand (of affected populations), environmental threats, and the numerous interactions required to coordinate relief organizations. This section discusses research papers related to the importance of operations management in the 2010 Haiti crisis and the role of technology in reducing uncertainty and improving response operations.

2.1 Dynamics and criticality of emergency operations management in the 2010 Haiti crisis

When mobilizing logistical capabilities in response to a disaster, it is crucial to consider both the timing and magnitude of the crisis. From a temporal perspective, the nature and risks of the response vary at each stage of relief deployment, a process known as the disaster management cycle (DMC) (Fuhrmann et al., 2008; Howden, 2009; Van Wassenhove, 2006). The DMC identifies the different phases and management tools used before, during, and after a disaster and usually comprises four phases: preparedness, response, recovery, and mitigation. Varvas (2013) defined the response phase as the immediate response stage and the time when regional, national, and international actors generate aid and support to those affected by a disaster. Due to the urgency of sufficient and timely assistance in the very first days following a disaster (Banomyong and Sopadang, 2010; Ichoua, 2010; Sever et al., 2006), logistics is the most essential function for providing vital aid such as water and food supplies (Howden, 2009). Operations during the response phase become even more critical as relief organizations face large-scale destruction and chaotic settings, which limit assessment and response capacities and increase coordination requirements (Holguín-Veras et al., 2012; Howden, 2009; Van Wassenhove and Pedraza Martinez, 2012).

This field research focuses on the first three months following the Haiti earthquake, a critical period that was fraught with both the need for large-scale emergency assistance as well as impediments in terms of large-scale destruction. Portilla and al. (2010) observed that the Haitian infrastructure was already vulnerable before the disaster and was almost completely

destroyed after it, which significantly impaired the safe and timely delivery of relief goods in the first months of the crisis. Most of the local logistical capacity, particularly the seaport and airport of the capital Port-Au-Prince, were severely impacted by the earthquake and remained nonfunctional during this period (Holguin et al., 2012). According to Van Wassenhove and Pedraza Martinez (2012), the scale of destruction caused by the disaster led to major bottlenecks in reaching the affected populations in the first months. The humanitarian community struggled to transport relief aid, which led to desperation, frustration, and violence within the affected populations (Ichoua, 2010). Varvas and McKenna (2013) observed that the magnitude of the disaster and the destruction of essential infrastructure in Haiti, such as the United Nations (UN) headquarters in Port-Au-Prince and the main channels of communication, slowed emergency response communication and effective assistance. In this manner, the Haiti crisis revealed the importance of improved coordination (Holguín-Veras et al., 2012), communication, and information exchange (Portilla et al., 2010), which can be facilitated by technology.

2.2 Importance of technology to improve information, communication, and coordination within humanitarian supply chains

The importance of technology has been widely discussed in the context of commercial supply chain management. From an organizational perspective, technology is said to be beneficial for increasing performance by improving flexibility, quality, and productivity (Melville et al., 2004) and facilitating customer–supplier relationships (Subramani, 2004). Most recent studies related to the use of technology within supply chains discuss the benefits gathered by radio frequency identification (RFID) technology for identifying and tracking supply flows and inventories using radio waves (Doyle, 2004; Shepard, 2005). According to Chow et al. (2007), RFID technology provides three main benefits: it identifies each individual item (e.g., material or vehicles), tracks item movements through the supply chain, and improves visibility and coordination among partners through information exchange. Considering a supply chain's environment from a broader perspective, Wagner et al., (2009) identified three types of information and communication technologies (ICT) that can support transportation management: communication, positioning, and sensor technologies. Such technologies can improve supply chain security by reducing thefts and damages of intransit supplies and supporting anti-terrorism by ensuring responsiveness, real-time visibility, and flexibility. However, numerous studies also reveal limitations encountered in the deployment of technology. In particular, Melville et al. (2004) observed that the benefits of technology can be limited by internal complementary

resources, inter-organizational competition, and power imbalances. In addition, Mileti et al. (1978) and Subramani (2004) argued that technology can lead to the development of larger and more complex organizations. Furthermore, Dong et al. (2009) and Rai et al. (2006) maintained that technology requires value drivers to facilitate integration between partners and improve organizational and supply chain performance. Consequently, achieving higher inter-organizational coordination, performance, and effective technology implementation among supply chain stakeholders demands in-depth organizational transformation, firm-level commitment, and acceptance of full knowledge and information sharing (Bendoly et al., 2007; Lai et al., 2006; Sharma et al., 2007). Rogers (1995) added that any innovation adoption is based on several criteria such as the innovation's levels of relative advantage, compatibility, or complexity. This study demonstrates not only the benefits of advanced space-based technologies but also the limitations and constraints in its deployment when managing emergency operations.

In the context of a catastrophic disaster, complexity increases due to the lack of accurate information that increases the overall uncertainty in evaluating the disaster's impact and the affected populations' needs. In particular, numerous relief organizations, including NGOs, governmental agencies, the military, and international organizations are involved during the disaster response stage, leading to several information sources and asymmetric needs assessments Sheu (2010). In this chaotic setting, technology can help address environmental uncertainty following the large-scale destruction of national infrastructure (Koudelka and Schrotter, 2007; Fuhrmann et al., 2008; Varvas, 2013). Holguin-Veras et al. (2012) highlighted the criticality of communication systems in reducing this uncertainty and matching supplies to needs. Technology is a leveraging tool for responding to a disaster by improving visibility, integration, and coordination between supply chain partners. Comfort (2007) asserted that technology is absolutely necessary to manage major threats and improve emergency response, and identified both traditional and advanced technologies for supporting humanitarian relief. Nevertheless, technology implementation and use within emergency supply chains can also encounter several difficulties. Van Wassenhove (2006) observed that communication with remote villages can be difficult because of weak infrastructure and large-scale destruction. From this point of view, the primary findings of a field survey among humanitarian workers deployed in Haiti, conducted by Varvas and McKenna (2013), demonstrated that traditional telecommunication technologies can better support relief operations than more advanced technologies, such as satellite-based technologies because they are easier to use, cheaper, and broadly deployed even in poor or remote villages. The role of RFID technology has also been

discussed in the context of disasters to support logistics center management (Yang et al., 2011), emergency response management (Tran et al., 2010), and information collection and dissemination on infrastructure or damage to buildings (Aziz et al., 2009). However, Yang et al. (2011) observed that RFID technology can become non-operational in the aftermath of large-scale disasters, such as earthquakes, hurricanes, or floods, due to damage of land-based cellular networks, leading to the inability to transmit data to a remote command center. In this context, satellite-based communication technology is absolutely essential to collect information from the field. Nevertheless, despite the increasing importance of satellite-based technologies in relief efforts, fewer studies that describe their roles and limitations have been published.

2.3 Types of technology used in emergency operations management

There are three main categories of technology used by relief logisticians: 1) telecommunication systems, 2) imagery and mapping systems, and 3) positioning devices. Most of them are enabled by earth-orbiting satellites and are called space-based technologies (United Nations, 2014). They promise timely, accurate, and resilient information and communication channels to support disaster management and emergency response.

2.3.1 Telecommunication systems

Communication technologies refer to all channels that provide voice communication and Internet access to send and receive data (Wagner et al., 2009). These are the vital links among the response organizations and are absolutely necessary for responding quickly to major disasters (Varvas, 2013). Comfort (2007) identified several telecommunication technologies such as radios, cell phones, landline phones, and satellite phones. Therefore, telecommunication systems can rely on either traditional or more advanced channels and this provides alternatives for different contexts. Traditional communication is a reliable mode of coordination during the early aftermath of a disaster, but it can be severely impacted and non-functional. Therefore, this critical period requires the use of emergency communication equipment, such as global mobile personal communication via satellites, for worldwide communication (Oh, 2003). In this context, satellite communication may be the only option for enabling voice calls or data exchange (Wagner et al., 2009). It can remain functional, be rapidly deployed, and facilitate relief activities when regular infrastructure is damaged or destroyed (Fuhrmann et al., 2008; Koudelka and Schrotter, 2007).

2.3.2 Imagery and mapping systems

Locating and assessing needs is the first priority in the aftermath of a catastrophic event. Therefore, relief organizations require a map-based view of the disaster area to quickly assess the needs and road conditions to ensure that their vehicles can reach the affected populations (Holguín-Veras et al., 2012; Prakash and Kulkarin, 2003). Disaster maps are mainly based on satellite imagery, but plane or drone imagery can provide more accurate information with higher resolution (Van Aardt et al., 2011). The processing techniques, called "mapping" (Joyce et al., 2009) or "remote sensing" (Holguín-Veras et al., 2012), require geographic information systems (GIS) to produce thematic maps of the impacted areas in the immediate hours after a disaster (Altan et al., 2010; Verjee, 2005). Space-based imagery provides critical information delivered in the form of satellite maps and helps plan responses in a timely manner in the aftermath of a disaster (United Nations, 2014). In the context of the Haiti crisis, Altan et al. (2010) observed that it can facilitate the damage assessment of infrastructure, such as road networks, bridges, warehouses, or airports, and identify the best locations for emergency support facilities and refugee camps, define a logistical plan, and prioritize delivery based on humanitarian needs. The main benefits of imagery and mapping systems include providing an overview of the impact of large-scale disasters (Matsuoka and Yamazaki, 2004) and facilitating visualization and communication of complex and dynamic information (Prakash and Kulkarin, 2003).

2.3.3 Positioning devices

Positioning devices are usually enabled with the global positioning system (GPS). The satellite system provides geographical coordinates that is received by positioning devices and used for both discrete localization and navigation from one point to another. Two satellite-based positioning technologies are used by relief organizations: handheld GPS devices and remote vehicle tracking devices.

GPS devices

In the aftermath of a large-scale disaster, relief teams are deployed in the field and can face difficulties in recognizing streets and buildings due to damage and rubble (Cutter, 2003). Portable positioning devices enable staff to determine exact locations and provide tools to select the positions of relevant areas of interest such as damaged infrastructure and displaced camps. Unlike mapping technologies, which use remote imagery, these devices can be defined as local

sensing technologies (Holguín-Veras et al., 2012). Many authors such as Manfré et al. (2012), Ramsey III et al. (2001), Chapma (2008), and Holguín-Veras et al. (2012) have highlighted the interest of relief organizations in using both remote space-based imagery to obtain large-scale geographical mapping and ground positioning devices to collect more accurate information.

Vehicle tracking devices

Transporting relief supplies to a disaster area requires the deployment and management of numerous vehicles in the field. Monitoring fleet capacity allocation, also called field vehicle fleet management (VFM) (Pedraza Martinez et al., 2011), can be critical for efficiently coordinating large-scale relief operations. Van Wassenhove and Pedraza Martinez (2012) identified three main objectives of a VFM system in humanitarian logistics: improving vehicle delivery, fleet availability, and cost effectiveness. In this complex setting, vehicle tracking technologies can improve VFM and logistics through enhanced transparency by providing real-time vehicle locations and paths (Blecken and Hellingrath, 2008; Holguín-Veras et al., 2012). One remote vehicle tracking technology is an autonomous GPS-based device installed in a vehicle that transmits several pieces of real-time data such as current positions, continuous movements, and predetermined reports and alerts to a remote command center. According to Blecken and Hellingrath (2008), tracking enables the prediction and timely adaptation of arrival times for orders. In the context of humanitarian operations management, Van Wassenhove et al. (2010) defined tracking as a process of determining the path followed by aid from origin to destination. It facilitates the determination of locations of in-transit field vehicles traveling to a disaster area, and consequently enhances the safety and security of staff on the ground in the case of attacks to or thefts of vehicles.

In the aftermath of large-scale disasters, space-based technologies can be crucial to assist relief operations management. They can provide spatial information inputs for mapping and localizing staff and vehicles on large-scale areas and enable resilient communication links via satellite. Remotely sensed image data from earth observation satellites or airborne instruments are indispensable for the timely provision of damage maps indicating the spatial differentiation of a disaster's impact. When integrated with *in situ* GPS data in GIS, they facilitate further thematic enhancement; for example, for localizing critical infrastructure, vulnerable objects, or risk areas (Altan et al., 2010).

2.4 Research methodologies used in the literature

Very few research methodologies have been applied to analyze the impact of technology on operations management. Regarding commercial logistics, Brand and Small (1995) proposed the value of information (VOI) approach as a decision support tool that can enable organizations to select different informational options by quantifying their benefits. The VOI approach evaluates the benefits in terms of uncertainty and risk reduction when acquiring additional information (Yokota and Thompson, 2004). In the field of transportation management, Wagner et al. (2009) defined the VOI methodology as the evaluation of the marginal improvement that a system achieves by adopting new technologies and obtaining additional information. However, the VOI approach does not consider either the perceived value added or the barriers encountered in implementing new information technologies. In the context of the post-2010 Haiti earthquake, Varvas and McKenna (2013) proposed a more in-depth analysis of the benefits and limits of adopting communication technologies through personal interviews with stakeholders involved in relief efforts. Their field research compared the use of traditional and more advanced technologies and provided practical recommendations for better technology deployment in a post-disaster context. Despite the interest in such an approach, their research has limited scope as it surveyed only 10 aid workers and did not consider relief transportation management.

To our knowledge, this is the first empirical study specifically dedicated to evaluate space-based technology deployment in emergency operations management. We analyzed the impact of space-based technologies in the context of the 2010 Haiti crisis in terms of their benefits to response logistics and the difficulties in their use. Field workers involved in emergency operations during the first three months of the Haiti disaster response period were contacted and surveyed. The grounded methodology provides valuable information and contributes to disseminating strategic and operational insights regarding space-based technology implementation and further operational improvements.

3. Research questions and methodology

A dearth of theoretical and methodological approaches for technology assessment within relief supply chains impedes the dissemination of technologies and awareness of their optimal benefits. To address this gap in the literature, this study undertakes more specific and in-depth exploratory empirical research on the value added by four space-based technologies for relief logistics, as experienced by a sample of field workers. First, the preparation for writing the case

research was based on exploratory semi-structured interviews as suggested by Fisher (2007). Second, a questionnaire survey was designed and disseminated to evaluate the benefits of space-based technologies for emergency operations management, as well as the existing technological barriers within and among relief organizations.

3.1 Research questions

This study evaluates the extent to which space-based technologies benefit emergency operations. Therefore, it focuses on assessing relief operators' perceptions when using space-based technologies. The results of this study facilitate the promotion and implementation of space-based technologies by highlighting their benefits and difficulties, and proposing recommendations for both logistics operators and managers. Indeed, our study addresses the following two questions:

- What is the level of benefit derived from space-based technologies for emergency operations management?
- What are the difficulties encountered, and their potential impacts, when space-based technologies are used in emergency operations management?

3.2 Questionnaire design

Our questionnaire was developed in two phases. First, we identified the relevant activities of emergency supply chains and the pertinent space-based technologies to be evaluated in the questionnaire. Second, we designed a three-part questionnaire that enabled us to address our research questions based on the first phase insights.

3.2.1 Identification of the relevant logistical activities

To identify the relevant activities of relief logistics and the space-based technologies used during the 2010 Haiti earthquake emergency response period, we followed the procedure proposed by Martilla and James (1977) and Kvist and Klefsjö (2006). This procedure involves combining exploratory semi-structured interviews with a literature review to capture the important activities to be further evaluated in a questionnaire. In our case, the interviews were conducted with a group of three expert logisticians deployed in Haiti in 2010 as well as three academic researchers.

The logistical activities, derived from the semi-structured interviews and the literature review, are listed in the first column of Table 1. When these activities were identified in the literature, their sources are cited in the second column of Table 1; those identified during the semi-structured interviews are marked with an "x" in the last column (lack of references are marked by "–"). This final list contains 14 logistical activities considered critical in humanitarian logistics and specifically for the 2010 Haiti crisis. Most of them (the first 13 activities) are related to operational issues, whereas the last activity addresses more organizational issues.

Table 1: Summary of critical logistical activities in the post-2010 Haiti earthquake period.

Logistical activities	Literature review	Interviews
Operational Level		
1) Needs assessment	Holguín-Veras et al. (2012); Howden, (2009); Van Wassenhove and Pedraza Martinez (2012)	x
2) Needs localization	Holguín-Veras et al. (2012)	x
3) Installation of support facilities	–	x
4) Evaluation of roads', facilities', and populations' accessibility	Prakash and Kulkarin (2003); Wagner et al. (2009); Fuhrmann et al. (2008); Koudelka and Schrotter (2007); Holguin et al. (2012); Van Wassenhove et al. (2010); Van Wassenhove and Pedraza Martinez (2012)	x
5) Logistical bottlenecks management	Van Wassenhove and Pedraza Martinez (2012); Pape et al. (2010); Yates and Paquette (2011); Pedraza Martinez et al. (2010)	x

6) Localization of existing assets and facilities	Altan et al. (2010)	x
7) Vehicle routing	Pedraza Martinez et al. (2011)	–
8) Regional road transport management (e.g., from the Dominican Republic to Haiti)	–	x
9) Local road transport management in Haiti (e.g., to distribution centers)	Pedraza Martinez et al. (2010); Van Wassenhove et al. (2010)	x
10) Distribution management (to beneficiaries)	Roy et al. (2012); Holguín-Veras et al. (2012); Ichoua (2010)	x
11) Re-ordering (re-planning of transportation and distribution)	–	x
12) Coordination	Holguín-Veras et al. (2012); Pedraza Martinez et al. (2011)	x
13) Safety and security management	Van Wassenhove and Pedraza Martinez (2012); Ichoua (2010); Roy et al. (2012); Van Wassenhove et al. (2010); Braga (2010); Gupta and Agrawal (2010); James (2010); Kolbe et al. (2010); Malow et al. (2010).	x
Organizational Level		
14) Decision making	Pedraza Martinez et al. (2010)	x

The procedure used to identify the pertinent activities of Haiti relief supply chains was replicated to identify the relevant space-based technologies. Four space-based technologies that can support relief operations were identified and a summary of these technologies is presented in Table 2.

Table 2: Summary of the four space-based technologies relevant in a post-disaster response period.

Space-based technologies	Literature review	Interviews
1) Imagery and mapping systems	Prakash and Kulkarin (2003); Van Aardt et al. (2011); Joyce et al. (2009); Holguín-Veras et al. (2012); Altan et al. (2010); Verjee (2005); Matsuoka and Yamazaki (2004); Butenuth et al. (2011); Roy et al. (2012); Ichoua (2010); Manfré et al. (2012); Oh (2003)	x
2) GPS devices	Manfré et al. (2012); Ramsey III et al. (2001); Chapma (2008); Holguín-Veras et al. (2012); Wagner et al. (2009); Oh (2003)	x
3) Telecommunication systems	Varvas (2013); Comfort (2007); Fuhrmann et al. (2008); Koudelka and Schrotter (2007); Oh (2003); Zimmermann (1995); Garshnek et al. (1998)	x
4) Vehicle tracking devices	Blecken and Hellingrath (2008); Holguín-Veras et al. (2012)	x

3.2.2 Questionnaire design

A questionnaire survey is a useful methodology for evaluating perceptions (Holweg and Miemczyk, 2002; Larson and Poist, 2004; Paquette et al., 2012). The objective of our survey is twofold, but required an additional contextual question to better characterize the specificity of emergency operations management in the post-2010 Haiti crisis period. Thus, the questionnaire was organized around three questions. Question 1 provides a contextual overview of the challenges faced by staff on the ground by identifying the most critical logistical activities when managing humanitarian operations. Question 2 assesses the benefits of space-based technologies for the same list of logistical activities. In addition, this study cross-analyzes these two questions to identify space-based technologies that are most beneficial for supporting critical logistical activities. Question 3 required participants to comment on restrictions or difficulties using the four space-based technologies. These constraints can be both technical (related to the technology itself) and organizational.

Questions 1 and 2 used five-point Likert scales as suggested by Hallikas et al. (2005), Ojha et al. (2014), and Varvas and McKenna (2013) in research on disaster management. These questions required respondents to select one of the precoded answers on the Likert scales (Figure 1). Each rating on the scales (1 = low, 2 = low medium, 3 = medium, 4 = medium high, 5 = high) was assigned to a definition and verbally explained to participants. In Question 1, an additional ranking table was provided to further enable respondents determine the most critical logistical activities. In Question 2, participants were given the opportunity to state whether the technology was used to manage any of the 14 activities (Figure 2). Question 3 is an open-ended question, which provided more flexibility for collecting qualitative data, identifying areas for improvement, and generating recommendations for better deployment of space-based technologies within emergency supply chains.

The preliminary version of the questionnaire was pretested with three expert logisticians and three researchers who agreed to review it by phone, complete it, and return the questionnaire. Based on their responses, only minor changes were made to the questionnaire's structure and wording. The final version of the questionnaire is available in the Appendix.

1.1. Needs assessment: ☐ N/A

Difficulty:	☐ 1 - Low	☐ 2 - Medium Low	☐ 3 - Medium	☐ 4 - Medium High	☐ 5 - High
Personal comments:					

Figure 1: Illustration of Question 1 for one of the 14 logistical activities (needs assessment).

2.1. Needs assessment:

Imagery and Mapping	☐ ***Technology used***	☐ ***Technology not used***			
Benefits:	☐ 1 - Low	☐ 2 - Medium Low	☐ 3 - Medium	☐ 4 - Medium High	☐ 5 - High
GPS devices	☐ ***Technology used***	☐ ***Technology not used***			
Benefits:	☐ 1 - Low	☐ 2 - Medium Low	☐ 3 - Medium	☐ 4 - Medium High	☐ 5 - High
Telecommunication systems	☐ ***Technology used***	☐ ***Technology not used***			
Benefits:	☐ 1 - Low	☐ 2 - Medium Low	☐ 3 - Medium	☐ 4 - Medium High	☐ 5 - High
Vehicle tracking	☐ ***Technology used***	☐ ***Technology not used***			
Benefits:	☐ 1 - Low	☐ 2 - Medium Low	☐ 3 - Medium	☐ 4 - Medium High	☐ 5 - High

Figure 2: Illustration of Question 2 for one of the 14 logistical activities (needs assessment).

3.3 Population under study, contact process, and representativeness

For the scope of this study, the survey population comprises members of the relief community who had been involved in decision making, with direct implications for relief logistics and aid transportation management, in the first three months of the Haiti crisis. Howden (2009) identified several types of humanitarian organizations, such as government agencies (e.g., the United States Agency for International Development), multilateral agencies (e.g., the World Food Programme), NGOs (e.g., Médecins Sans Frontières), and members of the International Federation of Red Cross and Red Crescent Societies. The contacts needed to construct the survey sample were provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) in its document called the "3W Who does What Where/Contact Management Directory" created in 2010 in the aftermath of the Haiti crisis to facilitate communication and coordination among relief partners. This directory contains 992 people deployed in Haiti in the very first days and weeks following the earthquake. It includes relief actors' names, organizations, job titles, e-mail addresses, and phone numbers. The large number of contacts in this document enabled us to target the people most relevant to the scope of our research. From this initial list, we removed 132 non-operational field actors such as journalists, clergy, economists, statisticians, and psychologists. We were left with a population of 860 actors

representing 229 organizations deployed in the field and involved in emergency operations management. The target group, and more importantly, the final participants, must reflect the diversity of the organizations listed in this document, which includes NGOs, public institutions, international organizations, and militaries.

As suggested by Cooper and Schindler (2006), we used a stratified sampling method in which participants were randomly extracted within different categories of relief organizations. The selected sample has to be proportional, which means that the number of participants selected within each of the categories should reflect the general distribution within the overall population. Since we anticipated that the e-mail accounts of several of these participants would not be active anymore, we contacted a larger proportion of participants by e-mail than earlier planned. We were left with an initial sample of 108 experts from the OCHA list. Based on this sample, we performed a standardized expert survey. We contacted the 108 selected experts by e-mail in which we provided the research objectives and the questionnaire, and found that 35 (32%) of them had inactive e-mail addresses. Of the 73 with active e-mail addresses, 44 experts (60%) were contacted. These 44 experts replied to our request, but seven of them declined to participate, yielding an acceptance rate of 84%. Finally, 36 individuals completed and returned the questionnaires, i.e., a response rate of 82%.

To ensure the validity of the initial sample (108 people) and the participating group (36 people), it was essential to verify their representativeness. We compared the proportion of various actors among the overall population in the OCHA list, the selected sample, and the effective participating group. We observed only a few small differences between the subgroups in the population, within the sample, and within effective participants. Both military and public actors are the least represented groups within the three subgroups. In contrast, international organizations such as the UN are well represented, whereas NGOs such as the French Red Cross or MSF are best represented. The participating group can be considered as a representative of the sample and the overall population; thus, we do not need to use weights or factors for any particular under- or over-represented subgroup. Table 3 presents the distribution of the overall population, the selected sample, and the effective participating group, filtered by organization type.

Table 3: Distributions of the overall population, contacted people (sample), and effective participants by organization type.

Strata	Overall population	%	Sample	%	Effective participants	%
NGOs	520	60%	66	61%	20	56%
International organizations	220	26%	30	28%	11	31%
Public actors	105	12%	9	8%	3	8%
Military actors	15	2%	3	3%	2	6%
TOTAL	860	100%	108	100%	36	100%

4. Results

Data obtained from the 36 returned questionnaires enabled us to identify trends within and between Questions 1, 2, and 3. In particular, the findings from the Likert scale responses to Questions 1 and 2 were used to develop descriptive statistics and calculate Spearman correlations between both questions. We reviewed the qualitative information from the responses to Question 3 and identified common difficulties across relief actors to develop categories. The results of the analysis for the three questions are presented in this section.

4.1 Question 1: difficulty in managing the 14 logistical activities

Question 1 provides a contextual understanding of emergency operations management in the post-2010 Haiti earthquake. It assesses the difficulty level in managing logistics, as observed by relief actors deployed in Haiti, using both a five-point Likert scale and a ranking table. For each logistical activity, Table 4 presents the results gathered by the median and standard deviation (SD) of scores provided by the Likert scales and the ranking table. The ranking score was determined by calculating a weighted sum, where the number of participants who ranked it

first had a weight of 3, the number of participants who ranked it second had a weight of 2, and the number of participants who ranked it third had a weight of 1.

The results gathered from the ranking table and the Likert scales enabled us to identify four critical activities. First, the results from the ranking table reveal four critical activities: "needs assessment" and "safety and security management," which obtained the same score (21), followed by "logistical bottlenecks management" (14) and "distribution management" (12). Second, the results from the Likert scales also indicate two difficult activities having a median score of 4 ("medium high" level of difficulty): "logistical bottlenecks management" and "distribution management." The remaining activities on the list had median scores of 3. Meanwhile, the results reveal that "logistical bottlenecks management" had an SD of 0.9, which shows that this activity was a main concern for the majority of participants. The remaining activities on the list had higher SDs, revealing a greater variation within the range of median scores.

Table 4: Level of difficulty in managing the 14 logistical activities.

Logistical activities	Median	SD	Ranking score
1. Needs assessment	3	1.3	21**
2. Needs localization	3	1.1	4
3. Installation of support facilities	3	1.1	6
4. Evaluation of roads', facilities' and populations' accessibility	3	1.1	6
5. Logistical bottlenecks management	4*	0.9	14**
6. Localization of existing assets and facilities	3	1.2	3
7. Vehicle routing	3	1.4	1
8. Regional road transport management	3	1.2	3
9. Local road transport management	3	1.2	1

10. Distribution management	4*	1.3	12**
11. Reordering	3	1.4	3
12. Coordination	3	1.0	6
13. Safety and security management	3	1.1	21**
14. Decision making	3	1.1	2

* Activities with a median score greater than 3.
** Activities with the highest scores in the "Top 3" ranking table.

4.2 Question 2: benefits of the four space-based technologies when managing relief logistics

Question 2 provided two types of information. First, it enabled us to evaluate the level of technology use by calculating the percentage of users for each of the four space-based technologies in terms of the 14 activities included in Question 1. Second, it enabled us to assess the level of benefit of the four space-based technologies in managing each of the 14 activities.

4.2.1 Level of use of the four space-based technologies

Relief workers do not have the same level of use of space-based technologies mainly because these technologies are not always available, or because they decide not to use them or to use alternative information and communication technologies. Table 5 presents the percentage of users for each of the four space-based technologies for the 14 logistical activities.

We observed that the mean percentage of users for the 14 activities is high and similar for three categories of technologies: imagery and mapping systems (52%), GPS devices (51%), and telecommunication systems (53%). The results also revealed that the percentages of users of these three categories of technologies are higher for the three critical activities identified in Question 1 than the average of the 14 activities. For the "needs assessment" activity, the percentages were 57% for imagery and mapping systems, 66% for GPS devices, and 79% for telecommunication systems. For the "distribution management" activity, the percentages were 56% for imagery and mapping systems, 58% for GPS devices, and 64% for telecommunication systems. For the "safety and security management" activity, the percentages were 63% for imagery and mapping systems, 54% for GPS devices, and 63% for telecommunication systems.

Two other results should be highlighted. First, the average use of vehicle tracking technology among participants is only 17%, which is the lowest among the technology categories; the percentage of use of this technology category is also very low for the critical activities. Second, despite the criticality of "logistical bottlenecks management", few participants used space-based technologies to support this activity.

Table 5: Percentage of users of the four space-based technologies in terms of the 14 logistical activities.

Logistical activities	Imagery & Mapping	GPS	Telecommunication	Vehicle Tracking
1. Needs assessment*	57%	66%	79%	23%
2. Needs localization	66%	76%	61%	26%
3. Localization of potential sites for support facilities	55%	52%	55%	14%
4. Evaluation of roads', facilities', and populations' accessibility	50%	55%	54%	23%
5. Logistical bottlenecks management*	37%	44%	46%	12%
6. Localization of existing assets and facilities	56%	63%	52%	15%
7. Vehicle routing	46%	46%	50%	19%
8. Regional transport management	31%	32%	40%	12%
9. Local transport management	50%	54%	40%	19%
10. Distribution*	56%	58%	64%	19%

11. Re-ordering	42%	42%	36%	15%
12. Coordination	62%	56%	54%	12%
13. Safety and security management*	63%	54%	63%	19%
14. Decision making	74%	63%	69%	19%
AVERAGE	52%	51%	53%	17%

* Critical activities identified in Question 1.

4.2.2 Level of benefit of the four space-based technologies

Through the Likert scales, participants assessed the level of benefit in using the four space-based technologies in terms of the 14 logistical activities. The results, including the median scores and the SDs, are detailed in Table 6. Technologies that achieved a median score greater than 3 are considered beneficial (4 = medium high level of benefit; 5 = high level of benefit). Several observations can be made from the median scores. First, only three out of the 14 logistical activities ("localization of potential sites for support facilities", "logistical bottlenecks management", and "regional transportation management") do not appear to benefit from the use of any space-based technology. A closer look at the results indicates that imagery and mapping systems receive the most benefit among the technology categories, helping manage 11 of the 14 activities. GPS devices represent the second most beneficial technology category, which complement those of imagery and mapping systems. The telecommunication systems category is beneficial for assessing needs and accessibility and improving safety and security, whereas the vehicle tracking devices category is only beneficial for routing.

Regarding the four most critical activities identified from the responses to Question 1, we observed that none of the four space-based technologies were useful for managing logistical bottlenecks. In contrast, both imagery and mapping systems and GPS devices were useful for assessing needs and managing distribution, and both imagery and mapping systems and telecommunication systems were useful for managing safety and security.

Table 6: Level of benefit of the four space-based technologies for the 14 logistical activities.

Logistical activities	Imagery & Mapping		GPS		Telecommunication		Vehicle tracking	
	score	SD	score	SD	score	SD	score	SD
1. Needs assessment**	4*	1.1	4*	1.3	4*	1.3	2	1.2
2. Needs localization	5*	1.0	4*	1.2	3	1.5	1	1.3
3. Localization of potential sites for support facilities	3	1.4	3	1.4	2	1.5	1	1.2
4. Evaluation of roads', facilities', and populations' accessibility	4*	1.3	4*	1.2	3.5*	1.4	2.5	1.3
5. Logistical bottlenecks management**	3	1.3	3	1.4	3	1.5	2	1.4
6. Localization of existing assets and facilities	4*	1.2	4*	1.3	2	1.2	1	1.2
7. Vehicle routing	3	1.4	3	1.4	3	1.5	4*	1.3
8. Regional transport management	3	1.3	3	1.5	3	1.6	3	1.5
9. Local transport management	4*	1.1	3	1.4	3	1.4	3	1.3
10. Distribution**	4*	1.2	4*	1.5	2	1.3	1	1.1
11. Re-ordering	3	1.1	2	1.3	3	1.3	2	1.2
12. Coordination	4*	1.1	4*	1.3	2.5	1.5	2	1.4
13. Safety and security	4*	1.3	3	1.4	4*	1.4	3	1.2

management**								
14. Decision making	4*	1.3	3	1.5	3	1.5	1	1.2

* Technology categories with a median score greater than 3 are considered beneficial.

** Four most critical activities identified from the responses to Question 1.

We have also computed Spearman correlations within and between Questions 1 and 2. Nevertheless, the analysis of Spearman correlations did not enable us to determine whether the responses were significantly correlated. We thus relied on a qualitative analysis, based on responses to Question 3, to better understand the link between emergency operations management and the use of space-based technologies, as described in Section 5. Figure 3 depicts the results discussed above for the whole emergency relief supply chain. A simplified process highlights the role of space-based technologies from the needs assessment phase to the final effective distribution to beneficiaries.

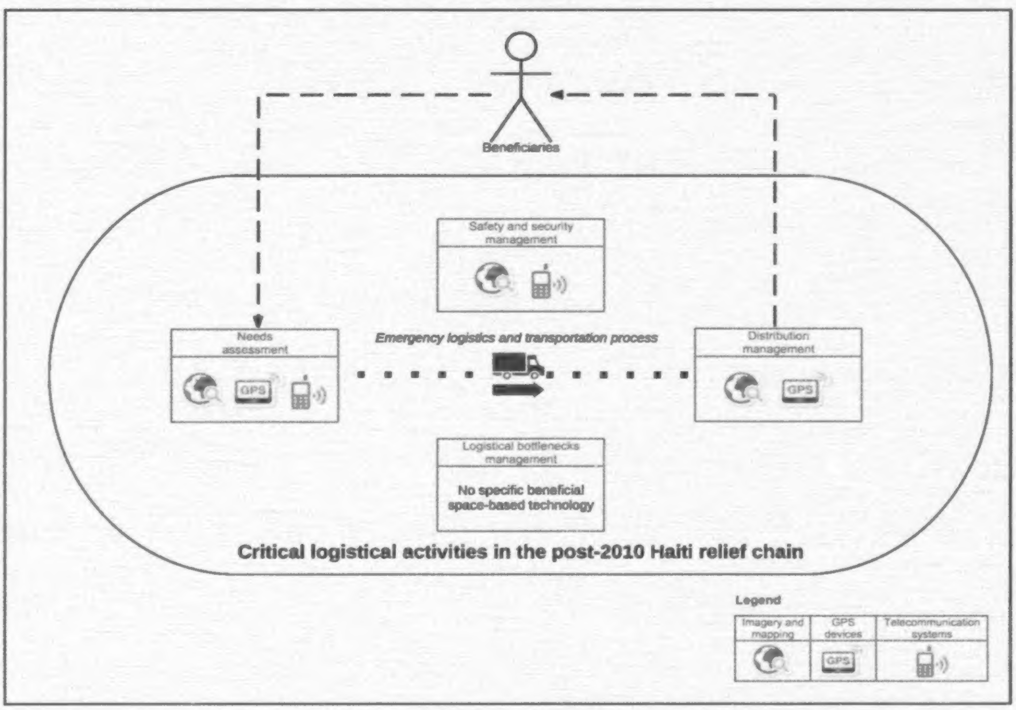

Figure 3: Four critical activities in the humanitarian supply chain and the corresponding beneficial technologies.

4.3 Results of Question 3: difficulties encountered in using space-based technologies

In responding to Question 3, participants had the opportunity to describe any difficulties they encountered in using each of the four space-based technologies. Both the words they used and the meanings were captured and segmented to maximize the information collection process and identify similar concepts and ideas (Gioia et al., 2012; L'Écuyer, 1990; Rourke et al., 1999). The qualitative data were filtered and categorized according to common difficulties experienced by the users (Dey, 1993). These difficulties were examined according to the different categories of space-based technologies.

4.3.1 Difficulties in using imagery and mapping systems

The participants described both the technical and non-technical difficulties they encountered in using imagery and mapping systems in emergency operations. From a technical perspective, they identified the lack of resolution of the satellite-based maps that is also amplified by the lack of regular updates of satellite imagery. From a non-technical perspective, the participants observed that imagery and mapping devices are very beneficial, but can be difficult to use, highlighting the significant lack of workers skilled in GIS within humanitarian organizations. These non-technical difficulties could lead to issues in assessing needs and identifying bottleneck sources.

4.3.2 Difficulties in using GPS devices

The participants observed three technical difficulties related to the use of GPS devices. First, they observed that the devices were too slow in providing the required data or service. Second, some of them mentioned that the GPS devices were inaccurate. Third, they experienced problems in integrating GPS data from different organizations. From a non-technical perspective, the participants explained that the devices produced GIS data that required more staff with relevant technological skills.

4.3.3 Difficulties in using telecommunication systems

The majority of participants highlighted the high cost of satellite-based telecommunication. Some also mentioned slow bandwidth speed when using the Internet to send and receive documents. Surprisingly, some participants also revealed that such telecommunication devices

could lead to negative externalities in terms of security such as the risks of theft or being attacked.

4.3.4 Difficulties in using vehicle tracking devices

Vehicle tracking is a GPS-based technology that enables managers to better identify vehicles' locations and trace their paths. Thus, the use of this technology also requires more staff with GIS skills who can interpret geographical information. However, most participants declared that vehicle tracking devices were not beneficial in the case of the Haiti earthquake. In particular, they argued that the devices would be more beneficial for routing and planning transportation operations on long distances and to remote areas.

5. Discussion

The analyzed responses to Questions 1, 2, and 3 highlight not only some important difficulties faced by relief actors in managing logistics but also some benefits and limits in using space-based technologies. This section discusses these difficulties and benefits. First, we discuss the main findings from Question 1 (i.e., the main difficulties of emergency operations management in the post-2010 Haiti earthquake period) by comparing them with related aspects in the literature. Second, we discuss the main findings from Questions 2 and 3 (i.e., the evaluation of the benefits and difficulties in using space-based technologies within relief supply chains).

5.1 Main challenges of emergency operations management

The foremost difficulty highlighted by the participants of this study concerns logistical bottlenecks management, which is related to major urban traffic congestion and delays in transporting and delivering aid to beneficiaries during response operations in Haiti. Pape et al. (2010) and Yates and Paquette (2011) highlighted such issues and observed that the large-scale destruction in Port-Au-Prince led to major bottlenecks and difficulties in reaching affected populations. Regarding local capacity, Van Wassenhove and Pedraza Martinez (2012) observed that the scarcity of equipment (e.g., 4×4 vehicles and helicopters) and resources (e.g., fuel) also contributed to bottlenecks and difficulties in transporting aid in the very first weeks.

The second most important difficulty revealed in this study concerns distribution management and refers to issues faced by participants in providing aid in a timely and safe

manner to the affected populations. Indeed, many difficulties occurred during the 2010 Haiti crisis while identifying distribution centers and securing supply flows (Ichoua, 2010). Government agencies as well as NGOs faced several problems in providing aid supplies to the affected populations, resulting in a large amount of desperation, frustration, and violence among those populations. Holguín-Veras et al. (2012) identified four factors that blocked distribution: the scale of required resources (e.g., staff requirements), the geographical scale of the disaster, the time available for delivering aid in a context where critical infrastructure is damaged or destroyed, and the large number of relief organizations deployed in the field leading to coordination issues in distributing aid to the beneficiaries.

The third most important difficulty encountered was needs assessment; that is, difficulties when evaluating aid requirements for people killed, injured, or displaced in terms of food, water, equipment, medical supplies, and staff. Portilla et al. (2010) also confirmed that the large-scale destruction in Haiti has led to impediments in assessing the real needs of the population because of communication issues and difficulties in receiving information from the field.

The fourth difficulty faced by the participants, safety and security management, refers to the management of thefts, losses, accidents, injuries, or attacks, including protection of both the disaster-affected population as well as the relief staff and materials (Roy et al., 2012). Numerous studies have also emphasized the security problems in Haiti such as those by Braga (2010), Gupta and Agrawal (2010), Ichoua (2010), James (2010), Kolbe et al. (2010), and Malow et al. (2010). However, the results of the Likert scales and ranking table reveal that some relief actors did not agree on the level of security risks in Haiti. The main reason is that a security threat is an individual perception linked to the organizational and geographical deployment contexts. For example, the French Red Cross benefited from the support of the MINUSTAH, the UN organization in charge of managing security and protecting the relief workers in Haiti. Thus, the participants from this organization did not mention any specific difficulty regarding security. From this perspective, Van Wassenhove et al. (2010) observed that some aid convoys received the protection of armed escorts against security threats. In contrast, the MSF participants explained that they did not benefit from the MINUSTAH security support, and thus, their perceptions of security risk was higher.

5.2 Benefits and difficulties of the deployment of space-based technologies: cross-analysis between the responses to Questions 2 and 3

The responses to Questions 2 and 3 demonstrate the benefits and difficulties for the deployment of four space-based technologies within relief supply chains. Accordingly, we organized these technologies into two categories on the basis of similarities in benefits, difficulties, and improvement opportunities. The first category comprises the space-based technologies that provide geographical information, including imagery and mapping systems, GPS devices, and vehicle tracking devices. The second category comprises the space-based technologies that provide communication access, namely, telecommunication systems.

5.2.1 Space-based technologies that provide geographical information

Imagery and mapping systems

The responses to Question 2 indicated that imagery and mapping systems are the most beneficial among the four space-based technology categories as they help manage three of the four most critical activities. First, imagery and mapping systems facilitated needs assessment, one of the very first required activities of relief organizations in the aftermath of a disaster. They are indeed useful for quickly assessing the situation and deploying relief supply chains. In the case of the 2010 Haiti earthquake, Altan et al. (2010) observed that they provided a clear picture of the situation to both the field staff and decision makers in the very first hours and days of the aftermath. In the general context of disaster response, Butenuth et al. (2011) also highlighted the benefits of these technologies for assessing damage of critical infrastructure and their accessibility, whereas Roy et al. (2012) highlighted the role of satellite mapping to improve the distribution management of aid to beneficiaries after supplies arrived. In the specific context of the 2010 Haiti crisis, Ichoua (2010) promoted the use of imagery and mapping systems for managing distribution operations. Finally, imagery and mapping systems can support safety and security management by giving an overall picture of the situation on the ground and preventing security issues. The United Nations Institute for Training and Research (2011) suggests that satellite-based imagery facilitates relief operations in some contexts constrained by security threats.

According to the participants, despite the benefits of imagery and mapping systems, they also posed some major difficulties and limitations. The responses to Question 3 as well as previous research highlighted two main concerns regarding the use of these systems: low

resolution and detail (Manfré et al., 2012) and insufficient real-time information (Butenuth et al., 2011; Chapma and Li, 2008; Cutter, 2003; Zlatanova et al., 2008). The results of this study also reveal the impacts of these two difficulties on emergency operations management in terms of needs assessment, distribution management, and safety and security management.

GPS devices

The responses to Question 2 reveal that GPS devices can facilitate satellite imagery by providing more accurate information. In particular, the lack of detail in satellite data, usually caused by limited spatial resolution within an urban context, might be solved through terrestrial mobile mapping systems such as GPS devices. The complementarity between satellite imagery and *in situ* GPS devices in a post-disaster context has been highlighted by Chapma and Li (2008), Cutter (2003), Manfré et al. (2012) and Ramsey III et al. (2001). Further, the responses also indicate that GPS devices can improve emergency operations management in terms of needs assessment by providing more precise ground information (e.g., the exact location and dimensions of refugee camps, damaged buildings, debris on the roads, and other points of interest). Moreover, they can improve aid distribution management by effectively determining the coordinates of actual and potential distribution centers. However, responses to Question 3 indicate that some GPS devices did not provide accurate coordinates (Wagner et al., 2009) of affected populations to the relief workers; this delayed needs assessments and impeded effective aid distribution to beneficiaries.

Vehicle tracking devices

The literature describes the role of vehicle tracking technology for facilitating vehicle routing as well as safety and security management by enabling near-real time adaptation to the ground situation evolution (Blecken and Hellingrath, 2008; Holguín-Veras et al., 2012; Lee and Whang, 2005; Marucheck et al., 2011). Nevertheless, responses to Questions 2 and 3 indicate that actors had neither the opportunity nor the desire to use it in their activities, and that this technology was only useful for vehicle routing. Regarding the role of vehicle tracking for security management, participants did not agree on its benefits in the case of the Haiti crisis for two main reasons. First, some participants did not face important security problems; thus, they did not require advanced support technologies. Second, the responses also demonstrate that the use of

alternative and more flexible technologies, such as telecommunication systems, seems to work better within a limited urban disaster area such as Port-au-Prince, which did not provide opportunities for the long-distance tracking of vehicles (Van Wassenhove and Pedraza Martinez, 2012).

5.2.2 Space-based telecommunication technology

Satellite-based telecommunication systems are very important in the first days of a disaster in remote locations when basic telecommunication systems are not fully functional (Conti, 2008; Varvas and McKenna, 2013). This technology helps achieve rapid flexibility and adaptability when information and communication can be critical to saving lives. The responses to Question 2 provide further information and indicate that this technology facilitated needs assessment and improved safety and security management in Haiti. However, responses to Question 3 reveal some important difficulties that limited the benefits of satellite-based telecommunication systems. First, the participants cited the cost of utilization as a main concern. Satellite-based telecommunication providers, such as well-known Inmarsat, have developed integrated solutions (devices and services) for the humanitarian community. The results reveal that the cost of satellite phone terminals (US$1,500–3,000) and prepaid SIM cards (US$1–2 per minute and US$5–7 per megabyte) was too expensive for many NGOs. Second, they criticized the limited bandwidth of such systems, which led to very slow information and data exchange. Third, some participants mentioned that the deployment of such expensive devices could also represent an additional threat by increasing the risk of thefts and hacks. To address these problems, Varvas and McKenna (2013) suggested prioritizing the use of more traditional communication systems such as very high frequency (VHF) radios, which work well even in remote villages, instead of more advanced systems such as satellite-based telecommunication systems, which are expensive and more difficult to use for most field actors.

5.3 Common limitations and difficulties in the deployment of the four space-based technologies

The responses to Question 3 highlight problems related to staff limitations within relief organizations. First, the lack of skilled field workers who can optimally use space-based technologies due to insufficient and regular training seemed to be a main concern of the study participants. This issue has also been highlighted in previous research (Blecken and Hellingrath, 2008; Holguín-Veras et al., 2012; Van Wassenhove, 2006). In particular, imagery and mapping systems, GPS devices, and vehicle tracking devices require staff skilled in GIS to maximize

these technologies' benefits for emergency operations management (Cutter, 2003; Manfré et al., 2012). In the post-2010 Haiti earthquake, Kovács et al. (2012) demonstrated that relief organizations had very few resources and time for training people to use technology because of the high criticality of this phase. Second, the results from this study indicate that the high level of turnover and volunteers within NGOs increased the difficulty of using space-based technologies to manage relief logistics. From this point of view, Varvas and McKenna (2013) and Van Wassenhove and Pedraza Martinez (2012) observed that both the lack of training and high staff turnover had negative impacts on capacity building and operation efficiency as procedures had to be continuously explained, causing delays in relief efforts. Third, the respondents highlighted that advanced technologies may increase complexity and difficulty. Simpler and more traditional technologies should thus be prioritized because they could help actors focus on what really matters during an emergency response. Finally, the participants expressed a desire for greater investment in preparedness before a disaster occurs such as more permanent staff and long-term and continuous training. In addition, Cutter (2003) concluded that the organizational culture of NGOs can impede the adoption of space-based technologies in disaster management and that leadership at the strategic level to facilitate change within the relief supply chain was essential.

6. Conclusions, limitations, and future research

The Haiti earthquake was an event the scale of which no relief organization had seen before and technology was crucial to connect people in the field, coordinate relief organizations and render the invisible more visible. Surprisingly, little is known about the use of technology in humanitarian supply chains. This study focused on building a bridge between technology use and emergency operations management to help relief organizations effectively promote and deploy space-based technologies at relevant stages in the relief supply chain. Our study demonstrates the essential role of space-based technologies that have fundamentally changed the manner in which humanitarian organizations manage their operations by reducing their response time and enabling the crisis to be monitored in near real-time.

Through a preliminary contextual question, we evaluated the specific difficulties related to operations management during an emergency response. The results of the study reveal that assessing population needs, managing logistical bottlenecks, distributing aid, and managing security threats were the most important difficulties to address. Thereafter, we assessed the benefits and difficulties of using four space-based technologies to tackle these difficulties. The

results inform managerial practice in two important ways. First, the results reveal that the space-based technologies were especially useful in the very first hours and days following the Haiti earthquake and regular infrastructure and systems were seriously damaged or destroyed. Imagery and mapping systems, GPS devices, and telecommunication systems helped assess needs and imagery and mapping systems and GPS devices, facilitating effective distribution management. Meanwhile, imagery and mapping technologies and telecommunication capacities ensured the overall security of operations. Second, the results identify several difficulties that should be addressed by managers to facilitate effective space-based technology adoption by relief workers and encourage the humanitarian community to be proactive rather than reactive. At the strategic level, the high proportion of temporary staff within NGOs combined with insufficient training opportunities led to serious difficulties in using space-based technologies and logistical delays. The participants of this study argued for the development of regular training in the disaster preparedness phase to ensure the effective and efficient deployment of space-based technologies during an emergency response. We recommend that relief organizations to consider the financial and human resources that are required for improving the use of technology in the field.

Finally, the research highlights that while none of the four space-based technologies are required to manage every logistical activity, their combined use can help organizations manage the majority of critical activities to ensure continuous and speedy aid delivery. In particular, the participants demonstrated that imagery and mapping systems can be combined with GPS devices to increase the level of accuracy of GIS data using ground information and facilitate needs assessment and distribution management. In addition, complementary telecommunication systems are necessary to manage security risks, which cannot be predicted using remote imagery and mapping systems. On the other hand, participants also demonstrated that traditional non-space-based technologies should be considered instead of advanced space-based technologies. From this point of view, organizations should further encourage employees to be flexible, i.e., recognizing which technologies (both space-based and non-space-based technologies) should be prioritized and combined to manage a specific humanitarian relief environment and supply chain context.

Despite useful insights, this study has also some limitations. First, the population was based on the OCHA contact database, which did not represent the overall community involved in Haiti in 2010. Nevertheless, we are confident that the large diversity of actors included in this list provided us with an in-depth understanding of the main benefits and issues related to space-

based technologies in the Haiti relief supply chain. Second, it is likely that we cannot generalize the results of this case study to the whole community of humanitarian organizations. In particular, there are still many small NGOs that do not use satellite-based technologies, and we cannot conclude whether managing logistics was less efficient. We assume, however, that most of the technological benefits, issues, and recommendations that are highlighted in this case study are relevant to the majority of urban humanitarian crisis responses. Finally, the results cannot be generalized to the commercial sector. Humanitarian supply chains have to face a high degree of uncertainty and risk and prioritize the speed of aid delivery to save lives. In such extreme conditions, space-based technologies are crucial to achieve effectiveness and to manage the lack of terrestrial information and communication networks. In commercial supply chains, space-based technologies can be too expensive as they compete with more traditional technologies. For industries such as petroleum and mining that operate in more remote and dangerous areas, where usual infrastructure is unreliable environments, the effective use of satellite-based technologies can be crucial to manage operations and achieve both effectiveness and security.

Further research is needed to better understand the full role, limitations, and ideal combinations of space-based and non-space-based technologies in the preparedness, response, and recovery phases of disaster management. Technology is transformational and the Haiti case enables us to glimpse into a future of a resilient disaster response. It is likely that international agreement initiatives such as the International Charter on Space and Major Disasters, and the European program Copernicus will facilitate the promotion of space-based technologies within the humanitarian community.

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Appendix: Questionnaire

Question 1. What was the level of difficulty in managing the following 14 logistical activities during the first three months of the crisis?

Please check "N/A" if you consider that you do not have the knowledge to assess a specific activity.

1.1. Needs assessment: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.2. Needs localization: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.3. Installation of support facilities: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.4. Evaluation of roads', facilities' and populations' accessibility: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.5. Logistical bottlenecks management: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.6. Localization of existing assets and facilities: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.7. Vehicle routing: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.8. Regional road transport management: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.9. Local road transport management in Haiti: ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.10. Distribution management (to beneficiaries): ☐ N/A
Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High
Personal comments:

1.11. Re-ordering: ☐ N/A

Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Personal comments:

1.12. Coordination: ☐ N/A

Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Personal comments:

1.13. Safety and security management: ☐ N/A

Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Personal comments:

1.14. Decision making: ☐ N/A

Difficulty: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Personal comments:

1.15. What are the three most critical activities of the above list (1.1-1.19)?

	Top 1	Top 2	Top 3
Number of the activity			

Question 2. What was the level of benefits of the four space-based technologies for managing the 14 logistical activities?

2.1. Needs assessment:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.2. Needs localization:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.3. Installation of support facilities:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.4. Evaluation of roads', facilities' and populations' accessibility:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication ☐ ***Technology used*** ☐ ***Technology not used***

systems

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.5. Logistical bottlenecks management:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.6. Localization of existing assets and facilities:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.7. Vehicle routing:

Imagery and ☐ ***Technology used*** ☐ ***Technology not used***

Mapping

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.8. Regional road transport management in Haiti:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.9. Local road transport management:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.10. Distribution management:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.11. Re-ordering:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.12. Coordination:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.13. Safety and security management:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

2.14. Decision making:

Imagery and Mapping ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

GPS devices ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Telecommunication systems ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Vehicle tracking ☐ ***Technology used*** ☐ ***Technology not used***

Benefits: ☐ 1 - Low ☐ 2 - Medium Low ☐ 3 - Medium ☐ 4 - Medium High ☐ 5 - High

Comments:

Question 3. What difficulties were encountered when using the four space-based technologies?

	If known: **Products/systems used**	General or specific **technical problems**	General or specific **capacity problems**	General or specific **impacts on logistics**
Imagery and Mapping				
GPS devices				
Telecommunication systems				
Vehicle tracking				

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